

GALEX J194419.33+491257.0: An Unusually Active SU UMa-Type Dwarf Nova with a Very Short Orbital Period in the Kepler Data

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Abstract

We studied the background dwarf nova of KIC 11412044 in the Kepler public data and identified it with GALEX J194419.33+491257.0. This object turned out to be a very active SU UMa-type dwarf nova having a mean supercycle of about 150 d and frequent normal outbursts having intervals of 4–10 d. The object showed strong persistent signal of the orbital variation with a period of 0.0528164(4) d (76.06 min) and superhumps with a typical period of 0.0548 d during superoutbursts. Most of the superoutbursts were accompanied by a precursor outburst. All these features are unusual for this very short orbital period. We succeeded in detecting the evolving stage of superhumps (stage A superhumps) and obtained a mass ratio of 0.141(2), which is unusually high for this orbital period. We suggest that the unusual outburst properties are a result of this high mass ratio. We suspect that this object is a member of the recently recognized class of cataclysmic variables (CVs) with a stripped core evolved secondary which are evolving toward AM CVn-type CVs. The present determination of the mass ratio using stage A superhumps makes the first case in such systems.

Key words: accretion, accretion disks — stars: dwarf novae — stars: individual (GALEX J194419.33+491257.0) — stars: novae, cataclysmic variables

1. Introduction

The Kepler mission (Borucki et al. 2010; Koch et al. 2010), which was aimed to detect extrasolar planets, has provided unprecedentedly sampled data on several cataclysmic variables (CVs). This satellite also recorded previously unknown CVs as by-products of the main target stars. The best documented example has been the background dwarf nova of KIC 4378554 (Barclay et al. 2012; Kato, Osaki 2013a). In addition to this object, the group Planet Hunters (Fischer et al. 2012) detected several candidate background CVs.¹

We studied one of these background dwarf novae, the one in the field of KIC 11412044 (hereafter J1944). This object was discovered by the Planet Hunters group as a background SU UMa-type dwarf nova of KIC 11412044, in which superoutbursts and frequent normal outbursts were recognized.² Since it was bright enough and it was frequently included in the aperture mask of KIC 11412044, the outburst behavior can be immediately recognized in Kepler SAP_FLUX light curve of KIC 11412044.

2. Data Analysis

We used Kepler public long cadence (LC) data (Q1–Q17) for analysis. Since the outbursts were immediately recognizable in each light curve of the Kepler target pixel images, we used a custom aperture consisting of 4–6 pixels showing outbursts as we did in the background dwarf nova of KIC 4378554 (Kato, Osaki 2013a). We used surrounding pixels to subtract the background from KIC 11412044. We further corrected small long-term baseline variations by subtracting a locally-weighted polynomial regression (LOWESS: Cleveland 1979) and spline functions. Since the quiescent magnitude is difficult to determine, we artificially set the level to be 22.0 mag.

3. Characterization and Identification of Object

3.1. Outburst Properties

The resultant light curve indicates that this object is an SU UMa-type dwarf nova with frequent outbursts (figure 1). There were eight observed superoutbursts, and from the regular pattern, another superoutburst most likely occurred between BJD 2455553 and 2455568 (a data gap in Q8) and we numbered the superoutburst and supercycle assuming that there is a superoutburst in this gap. The intervals between successive superoutbursts (supercycles) were in a range of 120–160 d. We determined the mean

¹ <<http://talk.planethunters.org/objects/APH51255246/discussions/DPH101e5xe>>.

² <<http://keplerlightcurves.blogspot.jp/2012/07/dwarf-novae-candidates-at-planet.html>>.

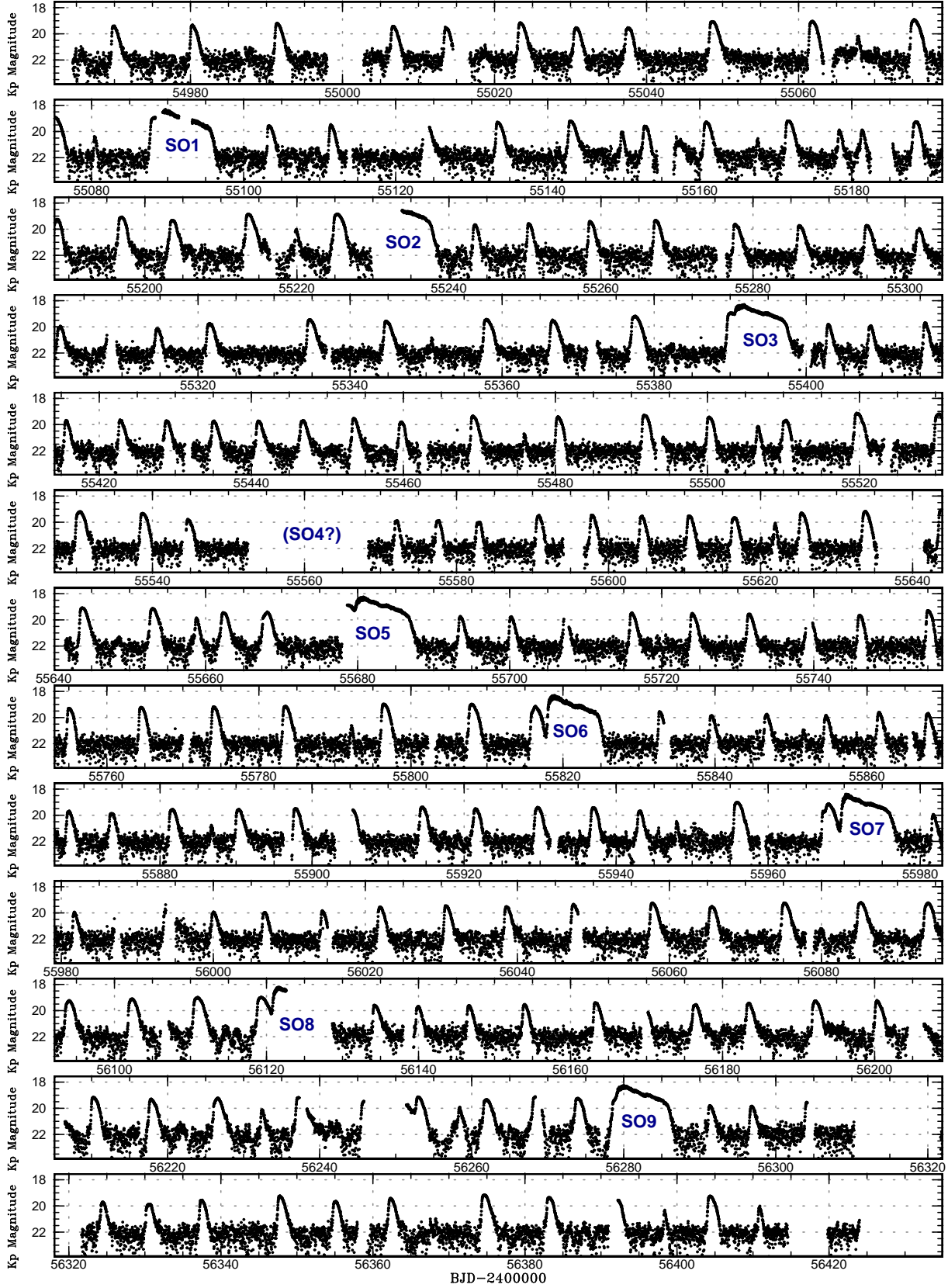


Fig. 1. The Kepler LC light curve of J1944. The superoutbursts are marked with labels.

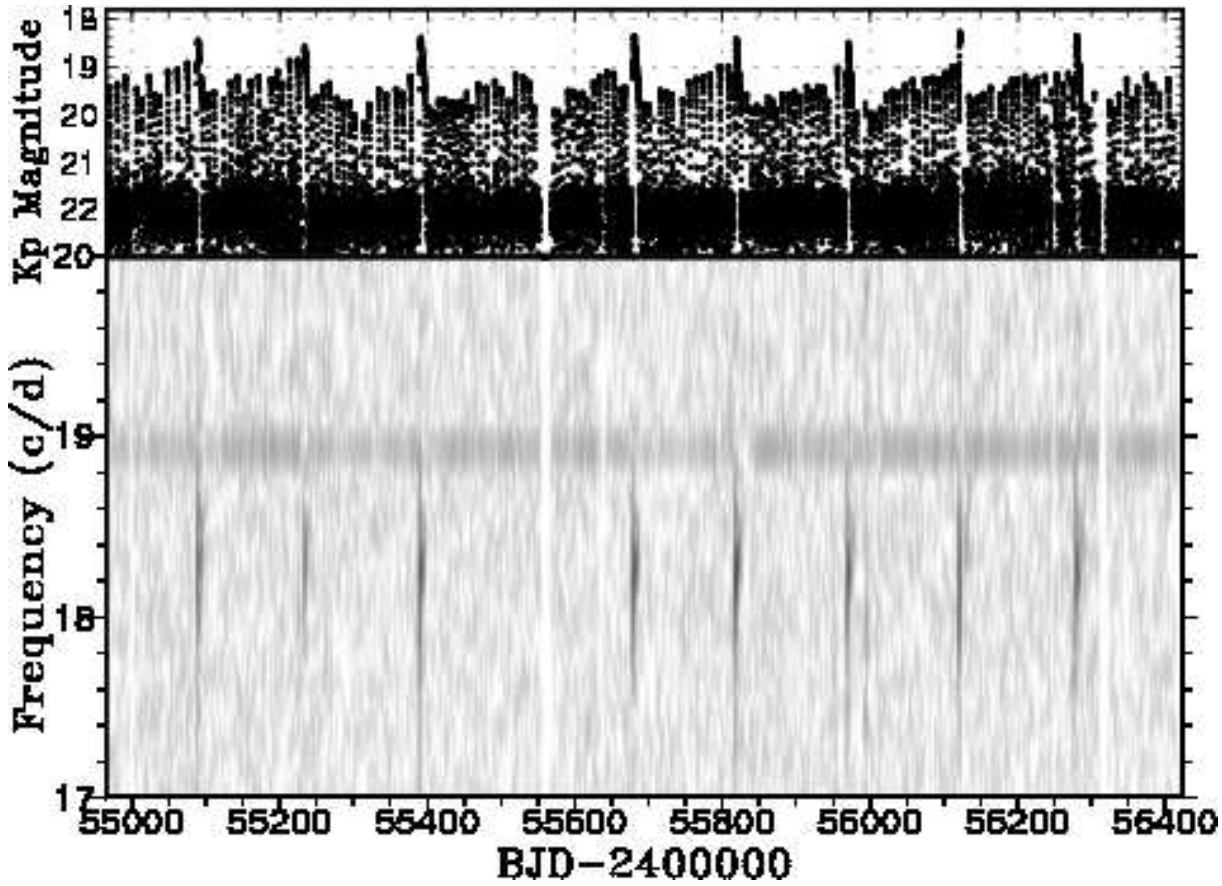


Fig. 2. Two-dimensional Fourier power spectrum of the Kepler LC light curve of J1944. (Upper:) Light curve; the Kepler data were binned to 0.08 d. (Lower:) Fourier power spectrum. The width of the sliding window and the time step used are 10 d and 1 d, respectively. The signal at frequency 18.93 cycle d^{-1} is constantly seen, and we interpret it as the orbital period. The broad signals around 18.1–18.5 cycle d^{-1} are superhumps.

supercycle of 147(1) d. Most of superoutbursts were associated with a precursor outburst with a various degree of separation from the main superoutburst. The typical duration of the superoutburst is ~ 8 d including the precursor part. This duration is shorter than those of many other SU UMa-type dwarf novae.

The number of normal outbursts in one supercycle ranged from 11 to 21. The intervals of normal outbursts were 4–10 d, one of the shortest known except ER UMa stars (Kato et al. 1999). The amplitudes of normal outbursts increased as the supercycle phase progresses. Some of the normal outbursts were “failed”, i.e. they decayed before reaching the full maximum.

3.2. Frequency Analysis and Source Identification

As shown in figure 2, a two-dimensional Fourier analysis (using the Hann window function) of the light curve of this object yielded two periods. There was a signal of a constant frequency (18.93 cycle d^{-1}) with the almost constant strength. Using all the data segment, we determined the period to be 0.0528164(4) d (18.934 cycle d^{-1}). We refer this signal to “0.0528 d” signal. Based on the high stability of the 0.0528 d signal during the entire Kepler observations, we identified this period to be the or-

bital period (P_{orb}) of this object. During superoutbursts, there were transient signals of superhumps at frequencies around 18.1–18.5 cycle d^{-1} as expected.

Let us now examine the source position of the background dwarf nova in figure 3. We checked the pixels which showed the dwarf nova-type variation. The peak of signal of dwarf nova-type outbursts was found two pixels away from the center of KIC 11412044 (star 1 on the DSS image). At this location, there is a GALEX (Martin et al. 2005) ultraviolet source GALEX J194419.33+491257.0 [NUV magnitude 21.3(3)] and we identified this source as the UV counterpart of this dwarf nova (figure 3, Q16), confirming the suggestion in the Planet Hunters’ page. The superhump component and 0.0528 d component were also confirmed at the location of this object (figure 3, Q14), and we consider that the 0.0528 d signal indeed comes from this dwarf nova. This has also been confirmed by the non-detection of the 0.0528 d signal in the SAP_FLUX of KIC 11412044 when this dwarf nova was outside the aperture of KIC 11412044.

3.3. Variation of Superhump Period

Since the superhump period is less than three LC exposures, it is difficult to determine the times of super-

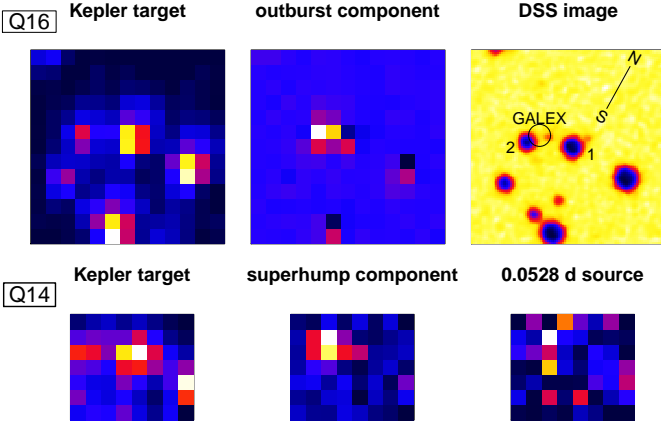


Fig. 3. (Upper panels): Q16 Kepler target pixel images (13×13 pixels). Brighter colors represent stronger signals except for the digitized sky survey (DSS) image. From left to right, flux of Kepler target pixels, outbursting component and the corresponding DSS image (the color level was reversed for better visibility). The main target KIC 11412044 (star 1 on the DSS image) is located at the center of the left image. There is a fainter star (star 2 on the DSS image) three pixels left to KIC 11412044. The middle image was created by subtracting the image in quiescence from the outburst image. The outbursting component is located two pixels (8 arcsec) left to KIC 11412044. There is a faint star between KIC 11412044 and star 2 on the DSS2 (blue plate, rotated to match the Kepler imaging direction) image (right image). This position is in good agreement with the location of the GALEX UV source.

(Lower panels): Q14 Kepler target pixel images (8×7 pixels). From left to right, flux of Kepler target pixels, superhumping component and 0.0528 d component. The locations of superhumping and 0.0528 d components are in good agreement with the outbursting component, i.e. two pixels left to KIC 11412044. These quarters were selected because Q16 has the widest field of view and Q14 contained a superoutburst. The pixel size of Kepler images is 3.98×3.98 arcsec.

hump maxima by the conventional method. We employed the Markov-chain Monte Carlo (MCMC) modeling used in Kato, Osaki (2013a). Although we only show the result of SO3 (figure 4), the pattern is similar in other superoutbursts. In the $O - C$ diagram, stages A–C (for an explanation of these stages, see Kato et al. 2009) can be recognized. Long-period superhumps (stage A superhumps) with growing superhumps were recorded during the late part of the precursor outburst to the maximum of the superoutburst. The overall pattern is very similar to those of other SU UMa-type dwarf novae, including V1504 Cyg and V344 Lyr (Osaki, Kato 2013; Osaki, Kato 2014). The object makes the fourth case (after V1504 Cyg, V344 Lyr and V516 Lyr) in the Kepler field in which the growing superhumps lead smoothly from the precursor to the main superoutburst and thus gives further support to the thermal-tidal instability (TTI) model (Osaki 1989) as the explanation for the superoutburst.

3.4. System Properties

The inferred fractional superhump period excess $\varepsilon \equiv P_{\text{SH}}/P_{\text{orb}} - 1$, where P_{SH} is the superhump period, of $\sim 3.8\%$ is, however, unusually large for this P_{orb} (cf. figure

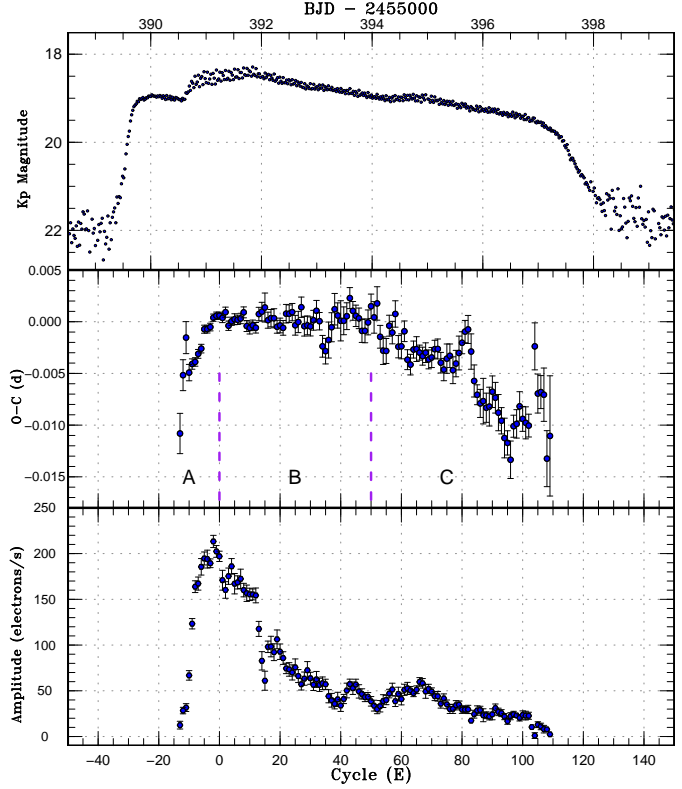


Fig. 4. $O - C$ diagram of SO3 of J1944. From top to bottom: (1): Kepler LC light curve. (2): $O - C$ diagram. The figure was drawn against a period of 0.05479 d. Stages A–C (cf. Kato et al. 2009) can be recognized. Long-period superhump (stage A superhumps) with growing superhumps were recorded during the late part of the precursor outburst to the maximum of the superoutburst. (3): Amplitudes in electrons s^{-1} .

15 in Kato et al. 2009).

Kato, Osaki (2013b) recently proposed that stage A superhumps can be used to determine the mass ratio ($q = M_2/M_1$) and the resultant mass ratios are as accurate as those obtained from eclipse modeling. We have succeeded in measuring the period of stage A superhump during the three superoutbursts: 0.0555(2) d (SO3), 0.05546(5) d (SO6), 0.05552(6) d (SO7). The corresponding fractional superhump excesses in the frequency unit $\varepsilon^* \equiv 1 - P_{\text{orb}}/P_{\text{SH}}$ are 4.8%, 4.77% and 4.88%. These values correspond to the q value of 0.14, 0.139 and 0.143, respectively. We therefore adopted $q=0.141(2)$. This mass ratio implies a massive (approximately two times more massive) secondary for this very short orbital period comparable to most WZ Sge-type dwarf novae (figure 5). This result may alternatively suggest the possibility of an unusually low-mass white dwarf. If we assume that the secondary of J1944 has a normal mass for this orbital period, such as $0.066M_{\odot}$ in WZ Sge (Kato, Osaki 2013b), the mass of the white dwarf must be $\sim 0.47M_{\odot}$. According to Zorotovic et al. (2011), the fraction of CVs having white dwarf lighter than $0.5M_{\odot}$ is only $7 \pm 3\%$, even including suspicious measurements. Furthermore, there is

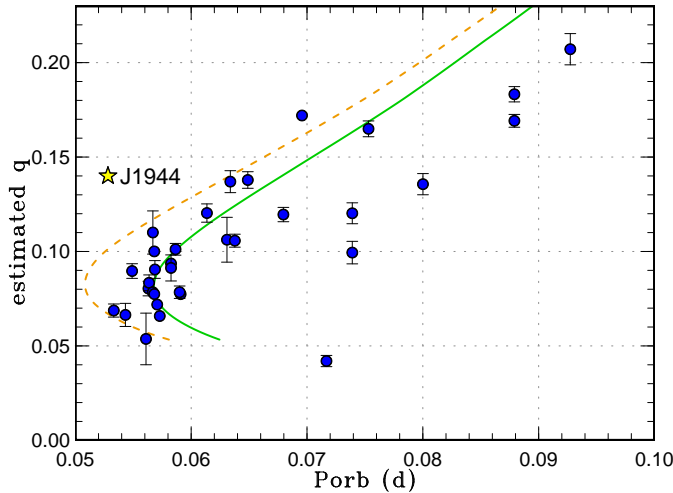


Fig. 5. Location of J1944 on the evolutionary track. The location of J1944 is plotted (star mark) on figure 5 of Kato, Osaki (2013b). The filled circles and filled squares represent q values determined using stage A superhumps and quiescent eclipses, respectively. The dashed and solid curves represent the standard and optimal evolutionary tracks in Knigge et al. (2011), respectively.

evidence from modern eclipse observations that mass of the white dwarf in short- P_{orb} CVs is not diverse (Savoury et al. 2011). We therefore consider the interpretation of a massive secondary more likely.

The presence of precursor outburst and the high frequency of normal outbursts are usual features of longer- P_{orb} systems such as V1504 Cyg and V344 Lyr. Systems with P_{orb} like J1944 are usually WZ Sge-type dwarf novae with very rare (super)outbursts (e.g. Kato et al. 2001) or ER UMa-type dwarf novae, a rare subgroup with very frequent outbursts and short supercycles (e.g. Kato, Kunjaya 1995; Robertson et al. 1995). J1944 does not match the properties of either group. This can be understood if the outburst properties are a reflection of the mass ratio rather than the orbital period since the q value of J1944 is closer to those of longer- P_{orb} SU UMa-type dwarf novae.

The presence of such a system would pose a problem in terms of the CV evolution since the secondary loses its mass during the CV evolution and q value is expected to be as low as ~ 0.08 around the orbital period of J1944. In recent years, some objects showing hydrogen lines in their spectra (this excludes the possibility of double-degenerate AM CVn-type systems) have been discovered around this period or even in shorter period. These objects include EI Psc (Uemura et al. 2002; Thorstensen et al. 2002), V485 Cen (Augusteijn et al. 1996) and GZ Cet (Imada et al. 2006). These objects are considered to be CVs whose secondary had an evolved core at the time of the contact, and are considered to be progenitors of AM CVn-type double white dwarfs (Podsiadlowski et al. 2003; Nelemans et al. 2004; Uemura et al. 2002; Thorstensen et al. 2002).

None of these objects have been reported for q determination directly from radial-velocity studies, and q values have only been inferred from the traditional ε , which

has an unknown uncertainty (Kato, Osaki 2013b). The detection of stage A superhumps in J1944 allowed the first reliable determination of q in such stripped-core ultracompact binaries. There is, however, a marked difference of the outburst frequency between J1944 and these known objects since the frequency of outbursts in such systems have been reported to be low (Thorstensen 2013). This suggests that J1944 has an anomalously high mass-transfer rate among these objects. The object may be in a phase analogous to ER UMa-type dwarf novae, whose high mass-transfer rates may be a result of a recent classical nova explosion (cf. Kato, Kunjaya 1995; Patterson et al. 2013). Since the object can be within the reach of the ground-based telescopes, the exact optical identification and the search for the feature of the secondary star are encouraged to solve the mystery.

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